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THE EFFECT OF EXPOSURE TO DICHOTIC NOISE ON THE DISCRIMINATION OF DICHOTIC TIME DIFFERENCES

SANFORD J. FREEDMAN

DONALD W. PFAFF

Massachusetts Mental Health Center

Boston, Massachusetts

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CHAPTER I.

Introduction

A. ABSTRACT.

Rearrangement experiments have demonstrated that subjects readily compensate for displacements of the visual field which are constant through time. Pseudophone experiments have shown similar compensation in audition, after rotation of the aural axis. Constantly changing displacement of the visual field, however, caused deterioration of visual-motor coordination. In each of these rearrangement and disarrangement experiments, specific types of body movements during the exposure period were necessary, if compensation or disorientation, respectively, were to occur.

~~In the present~~ experiment subjects were exposed, under three conditions of motility, to a constantly changing auditory field produced by two separate noise-generating systems, each feeding the sound into one ear. After two hours of continuous exposure, eleven out of twelve ambulatory subjects showed increased variability in an auditory localization task, the discrimination of dichotic time differences. Performance after two hours under the same conditions of exposure deteriorated for only five out of twelve subjects when body movements were restricted. When the subjects were wheeled in a wheelchair, sitting quietly except for frequent head rotations, nine out of twelve subjects showed increased variability. That is, self-produced motion of at least the head, while listening to dichotic noise which masked background sounds, was necessary to disrupt accurate auditory localization.

B. REASONS FOR THE EXPERIMENT

In the last decade, experimental psychologists have come to realize that sensory stimulation and motor activity should be regarded as part of the same set of sensory-motor functions, rather than being regarded as separate phenomena. von Holst (12) pointed out that the old model of sensory stimulation triggering the central nervous system to initiate a particular response has become outmoded. An important piece of evidence for this assertion is that electrical activity persists in deafferented parts of the nervous system. Sensory activity, therefore, does not always initiate motor activity. The next problem for the psychologist is to find out what effects motor impulses, which initiate muscle movement, have on the sense receptors. As von Holst has said, this approach studies the effects of the central nervous system on the periphery rather than the effects of the periphery on the central nervous system.

von Holst's model for effects of motor activity on sensory activity depends upon concept of "re-afference", or sensory feedback: The organism's motor activity causes some change in the organism's relation to its environment, and sensory information about this change (that is, re-afferent stimulation) is fed back to the organism. Summation, with regard to the sign and magnitude of the signals, of the efferent and the re-afferent signals determines perception.

One of the reasons for the present experiment is our desire to support general feedback-loop theory. Since von Holst's formulation generates specific hypotheses about the subject's behavior in defined conditions, the build-up of a set of confirming experiments is facilitated. Beyond that general aim, though, this experiment should provide evidence confirming Held's theoretical position (8), which is a development of von Holst's. Held has added a storage element to the Holstian model in order to use the reafference principle in accounting for relatively long-term adaptations to a displaced visual field; he has applied a feedback-loop explanation to changes in spatial coordination. In doing so, he is continuing another line of investigation, besides that of von Holst, for his concern with the rearrangement and disarrangement of spatial orientation makes it possible to relate his work to the sensory deprivation experiments which produce general visual disorientation.

One limitation of the evidence which Held has collected on the problem of re-afference in spatial coordination is that he has worked only in vision. The present experiment finds significance in (a) continuing Held's work in testing the Holstian model; (b) tracking down the factors crucial for maintainance of spatial orientation; and, most important (c) providing confirmation of Held's results in a different modality, audition.

CHAPTER II.

History of the Problem

A. REARRANGEMENT AND DISARRANGEMENT EXPERIMENTS.

1. Compensation for a constant displacement of the visual field.

In 1897 Stratton (19) performed the classic rearrangement experiment, studying vision under conditions where the retinal image was not inverted. He found that subjects readily adapted to such a displacement. Kohler and Erismann (13, 4) have done similar experiments in which "up" became "down" and "down" became "up", finding that subjects regained visual-motor coordination to the point where they could ride a motorcycle in traffic or climb mountains with their visual field thus inverted.

More recently Held and Bossom (9) had subjects walk in a normal environment wearing prisms which displaced the visual field 12 visual degrees to the left or right. Sixty-minute exposures produced significant shifts in an egocentric localization task in which the subject had to swivel in a chair and "line himself up" with a target. If the prisms displaced the visual field to the left, then the subject tended to center himself to the right of target, and *vice versa*, in the egocentric localization test; he was compensating for the alteration of his visual field caused by the prisms.

Held and Hein (10) trained subjects in a task in which the subject had to mark targets with a pencil. The apparatus was so arranged that the subject made his marks directly below reflected images of the targets. He could not see his hand, and could not, therefore, recognize and correct errors. The arrangement thus eliminated trial and error as a determiner of performance. The investigators found that if the subject wore prisms which displaced the visual field a fixed amount, his post-exposure target-marking shifted significantly in the direction opposite to the prismatic displacement. In another experiment Held and Hein (11) demonstrated that with suitably long exposure periods the compensating shift precisely balanced the prismatic displacement.

2. Compensation for constant displacement of the auditory field.

Held produced changes in subjects' binaural direction finding by the use of pseudophones during the training period (7). At the beginning of training in sound localization subjects tended to walk 45 degrees to the left of a sound source if the left microphone of a pseudophone led the right one by 45 degrees. If the right microphone led, then the subject tended, at first, to walk 45 degrees to the right of the sound source. After training, however, 13 of the 14 subjects had changed their localizations in the direction which compensated for the error induced by the pseudophones.

3. Exposure to a visual field whose displacement is constantly changing.

Cohen and Held (1) trained subjects to perform the same task used by Held and Hein (10, 11). They then exposed the subjects to a continuously shifting visual field displaced by movable prisms from 22 degrees left to 22 degrees right. The subject viewed his hand as he moved it back and forth during exposure periods ranging from 8 to 64 minutes. Under these conditions (and with a 30 minute exposure period) subjects showed a 34% increase in the standard deviation of their target-marking along a left-right axis. Increased variability ("disarrangement") is taken here to represent decreased accuracy of hand-eye coordination.

4. The present experiment.

The experiments described thus far demonstrated perceptual-motor rearrangement due to fixed displacements of the (a) visual and (b) auditory fields and disarrangement due to constantly changing displacement of the visual field. The present experiment completes the "set" by presenting a constantly changing auditory field to the subject during the exposure period. The details of the procedure are set forth in Chapter III.

B. THEORY.

The results of the rearrangement and disarrangement experiments cited above depended upon what the subject did during the exposure period. Motion initiated by the subject was found to be crucial in the production of a directional shift or of increased variability in the post-exposure test. Bossom and Held found that if the subject was wheeled in a wheelchair ("passive movement") instead of walking through his environment ("self-produced movement") there was no significant change in egocentric localization. Similarly, Held and Hein (10) found that, if the subject's hand was moved passively through the visual field, the significant shift of direction on the hand-eye coordination test, which resulted after self-produced movement, did not occur. In Cohen and Held's experiment, if the subject's hand was moved passively, no significant change in variability remained in the hand-eye coordination test.

Held and Hein (10) also found that some sensory information about the results of his self-produced motion had to be available to the subject if there was to be a significant shift of direction in the hand-eye coordination test. If the subject saw his stationary hand at the end of every two seconds' moving, then the significant directional shift occured; continuous viewing of the hand was not necessary.

Obtaining re-afferent stimulation as a result of self-induced movement, then, was necessary and sufficient to cause directional shifts after exposure to a constantly displaced visual field. The same two components, self-produced motion and re-afference were necessary to cause increased variability in the hand-eye coordination test after exposure to a constantly changing displacement of the visual field. To account for these findings Held has built upon the theory of von Holst and other experimentors. His model for the role of re-afferent stimulation in spatial coordination may be summarized as follows (8): Some part of the central nervous system monitors the efferent signals which activate any motor system. The signals are characterized by sign and by magnitude. Such signals are stored in the central nervous system, each paired with the re-afferent signals which resulted from the stimulation of sensory receptors accompanying the motor act. Upon reception by the central nervous system the re-afferent signal is compared to all other re-afferent signals which have been stored in connection with efferents identical in sign and magnitude to the efferent just signaled. That is, the sensory concomitant of the present motor act is being compared with the sensory concomitants of all identical motor acts previously performed. According to Held, the result of such a comparison determines subsequent perceptual-motor performance.

There are two ways to prevent the pairing of signals, efferent and re-afferent, and comparison with previous pairs in the storage. One way is to induce motion in such a way that minimum efference will occur. This is the case in the "passive movement" conditions described above. The subject is moving, but is not moving himself; no motor activity on his part is required. The other way to interfere with the efferent-reafferent pairing is to obstruct the feedback loop which allows the re-afferent signal to reach the central nervous system. This was done when the subject was not allowed to see the results of his self-induced movement. When the signal pairs are not available for comparison there is no basis for adaptation to a displacement of the visual field, for there is no way to recognize consistent differences between the present and past experience. In conditions where the subject is either moved passively or is not allowed to see the results of his movement, then, no shifts in egocentric localization or hand-eye coordination are expected.

Another way to disturb the adaptation process is to make the efferent-reafferent relationships ambiguous. The short exposure times necessary to cause adaptation in Held's rearrangement experiments suggest that recently stored pairs of signals are selected first for comparison or are more heavily weighted. If, for a given type of efferent signal, there have recently been stored many different types of re-afferent signals, then during the post-exposure testing when an identical efferent signal (with its paired re-afferent) is monitored, a number of different re-afferent signals may, with equal likelihood, be brought from storage. The ambiguity resulting in the comparison will be reflected in more variable performance on the post-exposure coordination test. Such a condition, Held says, exists when the subject is moving his hand and watching it through the variable prisms. Although the prisms are displacing the visual field back and forth in a systematic manner, there is no systematic way in which a given type of hand movement is related to the concomitant visual re-afferent stimulation. In the language of the model, there will be many different types of re-afferents paired with each type of efferent. Ambiguity of trace comparison causes increased variability of hand-eye co-ordination.

There is a localization task inherent in the tests used in Held's re-arrangement and disarrangement experiments. The egocentric localization test forces the subject to localize target in his visual field and to align his body with it. The hand-eye coordination test forces him to localize a target in his visual field and move his hand with respect to it. Therefore, an auditory localization test is appropriate for the auditory analogue of Cohen and Held's variable prism experiment (1). In the present experiment the localization task involved the subject's saying "left", "center" or "right" to each of a series of clicks.* If an auditory experiment

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* The signal, which the subject heard as a click, was actually a train of five pairs of electrical impulses. In each pair, one impulse went to the left ear and one to the right. The different trains of impulses varied only in the interval (in microseconds) between the impulses in each pair. The clicks heard by the subject could be localized inside his head as being on the left or right of the median plane.

using this criterion task is to fit into Held's set of experiments and is to have relevance to his theoretical model, then two propositions must be accepted. The first is that saying "left", "center", or "right" in a localization task is the equivalent (for the purposes of the feedback loop model) of reaching or turning left or right. This proposition raises the question of the differences between perception and perceptual-motor co-ordination, a question whose full treatment lies outside the scope of this paper. It must be said, however, that the very concept of feedback loops in sensory-motor systems implies that sensory events and motor events are not always discrete; this consideration, in turn, implies that the perceptual task of locating a sound may be equivalent to the perceptual-motor task of moving with reference to the sound.

C. THE PSYCHOPHYSICS OF AUDITORY LOCALIZATION.

The second assumption involved in applying an experiment using dichotic time difference discriminations to Held's set of experiments is that dichotic time differences are, indeed, an important cue for auditory localization.

Experimenters are agreed that there are three main determinants of auditory localization: dichotic differences in time, intensity and phase (18). Phase cues, however, are important only for continued tones (18). The signals localized in the present experiment were clicks of many different frequencies, and each of the impulses composing the clicks was only of .01 millisecond duration. This consideration leaves dichotic intensity and time differences as possible cues for localization in this experiment.

The results of A. W. Mills (14) indicate that intensity cues are crucial for localization when the signals are high frequency tones. Part of the procedure of the present experiment, though, was to have the subject equalize apparent intensities of the clicks at the two ears. The signals in the subsequent localization tests (pre- and post-exposure) differed only in dichotic time differences, not in dichotic intensity differences. Discriminations on the tests, therefore, must have been based on time cues and not on intensity cues.

Physiological experiments further support the use of dichotic time differences for an auditory localization test by indicating how time cues might indicate direction. Recording from the auditory cortices of cats Rosenzweig (15) found that if signals were presented separately to the two ears, the cortical response of the signal presented later in time could be inhibited. From differences of 0.2 to 9 or 10.0 milliseconds the amplitude of the response to the later signal was definitely smaller. For intervals above 10 milliseconds the response was nearer to full amplitude. Rosenzweig and Sutton (16) found a similar inhibition of the later signal at the level of the lateral lemniscus. Working on guinea pigs, Deatherage and Hirsh (2) demonstrated that the nervous system may compound intensity and time cues. They found that signals of greater intensity have shorter latency, and so dichotic intensity differences may be represented as dichotic time differences.

The argument here is not meant to summarize the research on auditory localization. Rather, it is meant to show that the discriminations in the criterion task of this experiment must have been based on dichotic time differences and that dichotic time differences have a role in auditory localization.

D. SENSORY DEPRIVATION EXPERIMENTS

Arguments have been presented to show how an auditory experiment using tests of dichotic time difference discrimination would fit into Held's set of experiments. The rearrangement or disarrangement introduced in these experiments may be regarded as selective examples of the generalized visual disorientation resulting from sensory deprivation. Hebb and his students did the original sensory deprivation experiments and, for instance, Doane (3) reported that after three to six days of isolation significant changes were found on tests of figural after-effects, size constancy, auto-kinetic effect, color adaptation and after-movement. Freedman et al (5) reported similar perceptual distortion after only eight hours of isolation. The present experiment is meant to attack the general problem of how the organism orients itself in its environment, but, in the manner of the rearrangement and disarrangement experiments, attempts to select out well-defined factors which may be crucial for orientation. When the mechanisms of specific orienting functions are understood, more light may be shed on the general disorienting effects of sensory deprivation. In this experiment the specific orienting function studied is auditory localization.

E. SUMMARY

This experiment is designed to test Held's reafference theory, a theory which may describe how perceptual-motor coordination is developed and maintained. The theory has found confirmation in the results of experiments which show how visual- and auditory-motor coordination may be rearranged or disarranged. The criterion task in this experiment is based on the discrimination of dichotic time differences, cues which have been shown to be important for auditory localization.

CHAPTER III.

The Experiment

A. HYPOTHESES.

Movement during the exposure period and sensory information about the results of movement are necessary to produce directional shifts or increased variability in rearrangement and disarrangement experiments respectively (1, 9, 10, 11) (see page 6). In this experiment the constantly changing sensory field is produced by two noise generators, each of which supplies the noise for one ear.* This arrangement causes a random distribution of time differences between the two ears.

Following the results of Cohen and Held (1) and the predictions of Held's correlator-storage model (8) one would expect a subject who had been walking around listening to the "white" noise to manifest increased variability on the post-exposure test of dichotic time difference discrimination. If the subject's movement was restricted, however, the number of efferent signals would be minimal (that is, minimal ambiguity from efferent-reafferent pairing could occur) and no deterioration in performance would be expected. In a restricted movement condition, then,

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* Each system generates the internal noise of a transistor, amplified by a circuit designed by Mr. Bernard Tursky, Massachusetts Mental Health Center.

variability of discriminations should be about the same for pre- and post-exposure tests.

A third condition used in this experiment combined elements of the first two conditions (walking, and lying down with restricted movement during exposure): The subject sat in a wheelchair so that his trunk and legs were not moved. He was instructed to rotate his head frequently in a horizontal plane. If gross body movement, as opposed to head rotation, is the crucial factor in the maintainance of accurate auditory localization, then one would expect no change in performance. That is, since the body is passive in the wheelchair ("passive movement") condition, the results should be the same as in the lying-down ("recumbent") condition, if body movements are crucial. If head rotations are crucial, though, one would expect increased variability on the post-exposure test.

To summarize, with any exposure condition in which the subject is moving parts of his body important in sound localization while also listening to the "white" noise, increased variability of performance is expected on the post-exposure auditory localization test. Both the critical motion and the dichotic "white" noise are required for changes to occur.

B. PROCEDURE.

1. Testing apparatus.

A train of five pairs of electrical impulses was generated by three Tektronix Inc. Type 162 Waveform Generators and two Type 161 Waveform Generators. (See Fig. 1.) The train was 40 milliseconds in duration, with pairs of .01 millisecond square waves spaced at 8 millisecond intervals. Of each pair of square waves, one pulse went to one side, and the other pulse went to the other side of the system. The interval between the pulses in each pair was continuously variable from 5 microseconds to more than 1 millisecond. A crossover switch permitted the signal to lead on either side.

The stimulus train was fed into Borg Type 205 potentiometers used as attenuators. A range of 4 decibels (100,000 ohms) was used. One attenuator modified the signal for each side, and the signal was then fed into Permoflux PDR8 stereophonic earphones, producing sharp clicks. The subject could equalize apparent intensity by manipulating the two potentiometer dials.

2. Exposure apparatus.

The noise generator for each ear fed the sound into a Realistic 8-transistor portable radio for amplification. The earphones used were a second set of Permoflux PDR8's. (See Fig. 2.) The energy spectrum of the noise from 200 to 3600 cps is shown in Fig. 3. The subject adjusted the intensity of the noise at the beginning of the exposure period to mask background noise.

3. Sample and pre-testing.

The experimental sample was composed of 18 naive Harvard undergraduates. None of the subjects were previously known to the experimenter, and those applicants who had extensive experience as subjects in other psychological experiments were not accepted. Psychology and Social Relations concentrators were also refused.

Two subjects began the experiment, but dropped out because the "white" noise caused ringing in their ears for two or three days. A third dropped out because of sickness, and a fourth because he was unavailable for 1 1/2 months after his first experimental session. Two other subjects completed the experiment, but their data could not be included in the results because on some of the post-exposure tests their subjective midpoints (in terms of dichotic time differences) had shifted far to one side and no numerical thresholds for discrimination were calculable. This problem is further explained in Chapter IV.

All of the 12 subjects remaining in the sample were trained in the dichotic time difference discrimination task on a separate day before the experiment began. The 12 were roughly equivalent in their skill at the task at the beginning of the experiment. Nine other applicants were rejected because they did not improve during the training period to the required level of skill.

In working out the testing and exposure procedures, 5 subjects were used for pilot study. None of them are included in the experimental sample. From this group the approximate level of discrimination required for the experiment was determined. When subjects required an average of more than 100 microseconds shift in dichotic time difference to perceive a change in the apparent localization of the fused clicks, the expected effect of increased variability of discriminations after exposure in the Ambulatory condition never appeared. With discriminations of the order of 30 microseconds, however, increases in variability (that is, deterioration to levels of discrimination worse than 30 microseconds) resulted in the Ambulatory condition. In order to be accepted for the experiment, therefore, subjects had to make discriminations of the order of 30 microseconds during the training period.

4. Procedure.*

On each experimental day the subject began and finished by equalizing the apparent intensities for the two ears. (See Fig. 4 for a sample data sheet.) The numbers of the data sheet refer to the units on the potentiometer dials, each unit representing 100 ohms of impedence. The order of the numbers is reversed; "000" on the dials indicates maximum attenuation. The dials were set alternately at Left = 550 and Right = 550, with the other dial set at 450 in each case. The subject localized the sound for each pair of settings and turned up the intensity on the weaker side (the side opposite that where the sound was localized.) An average (Left minus Right) reading was obtained for the set of six trials, and was used for the experimental setting with the total (Left plus Right) always equal to 1000.

Then the pre-exposure test of dichotic time difference discrimination was performed. (See Fig. 5 for a sample data sheet.) Starting with the click leading in the left ear by 90 microseconds, the signal was advanced towards right-lead in 5 microsecond steps until four successive "rights" were reported. The same procedure was then followed in

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*The instructions for all tests and exposure periods are included in Appendix A.

the opposite direction. Five such pairs of increasing and decreasing series were used for each test sitting. The set of thresholds of discrimination of change in the apparent location of the fused clicks (indicated by triangular markers in Fig. 5) provided a measure of variability.

On each experimental day, the subject was tested for dichotic time difference discrimination before exposure and at the end of each hour. On the average, a test took four minutes to complete.

Three two-hour exposure conditions were used:

1. Ambulatory - The subject was required to walk up and down a busy corridor for alternate five minute periods, insuring considerable head and body movement, both translation and rotation. (Fig. 6.) Continuous "white" noise was supplied by the two noise generators. At the beginning of exposure the subject adjusted the intensity of the noise just to the point where background noise was masked, and balanced the apparent intensity of the noise at the two ears. During the "resting" five minute intervals, the subject sat and read.

2. Recumbent - The subject lay on a bed with no head rotation and very little gross body movement. "White" noise was the same. The subject usually read throughout the exposure period, and was not allowed to sleep. (Fig. 7.)

3. Passive movement - The subject was wheeled in a wheelchair for alternate five minute periods over the same route as in the Ambulatory condition, and sat still (reading) in the intervals. (Fig. 8.) "White" noise was the same. Head rotations were frequent, while gross body movements were restricted.

Each subject was run in each experimental condition, with sessions spaced about one week apart. The sequence of conditions was permuted to control for order effects.

5. Criticisms and controls.

(a) Control of the effect of suggestion: In a perceptual task as difficult as the discrimination test used in this experiment precautions against suggestion must be specified, especially since the experimenter knew what results the hypotheses predicted. One cue to the subject in this experiment might have been the rhythm with which the stimuli were presented to the subject; for instance, a decrease in the frequency of presentation might indicate to the subject that he had reached the point where a change from "left" to "right" (or "right" to "left") was expected. Throughout the experiment, however, the rhythm was held constant at about 1 stimulus every 3 seconds. In addition, all data sheets and relevant dials were covered so that the subject couldn't see them, and no spoken communication (except for instructions, printed in Appendix A) occurred between the experimenter and subject after the beginning of each experimental session. As was evident from their comments at the end of their participation none of the subjects had any idea about the purpose of the experiment. According to their reports, none of themeven realized that the sound in the dichotic time difference discrimination tests moved systematically from right to left and vice versa.

(b) Fatigue, boredom and distraction.

The experimental hypothesis predicts that exposure in the Ambulatory condition shall cause increased variability on the dichotic time difference discrimination test and that exposure in the Recumbent condition shall not cause any change. If fatigue, boredom or distraction from the "white" noise itself affects performance it would affect results in the Recumbent as well as in the Ambulatory post-exposure tests. The hypothesis is that "white" noise will affect performance, therefore, but independently of those three factors.

Since increased variability was expected in the Ambulatory post-exposure testing, control conditions were used to determine the effects of fatigue, boredom and distraction from walking up and down the corridor:

1. Four subjects were run in a condition identical to the Ambulatory condition except that their hearing was unimpeded; they did not listen to "white" noise.

2. Three subjects were run for an extra 1/2 hour on their Ambulatory days. Following their post-exposure tests, they walked up and down the corridor continuously for the 1/2 hour and were then re-tested.

3. To determine the duration of the experimental effect in the Ambulatory condition, four subjects rested for an extra 1/2 hour on their Ambulatory days, and were then re-tested. During the 1/2 hour period they walked occasionally, but sat reading most of the time.

Two subjects were run in additional 1/2 hour control conditions following the passive movement condition. One subject sat and read for the 1/2 hour, and the other was continued in the Passive movement condition, except that he was not listening to the "white" noise.

Five subjects returned after they had finished the experiment *per se* to repeat some of the experimental sessions. They were subjects whose results had deviated considerably from the sample mean, and it was hoped that extra information might be obtained by running them in extra conditions and controls. The data from such extra sessions is stated as such and is not included in the table of experimental results.

C. RESULTS AND DISCUSSION.

1. Statistics.

The hypotheses in this experiment are concerned with change in variability of performance. The set of ten thresholds, obtained by the procedure described above, provide a measure of variability. For a given experimental session, then, comparison of the standard deviations of the set of thresholds from the pre- and post-exposure tests was the measure of increased variability. The standard parametric test for the significance of the difference between two variances is the F-test, which assumes an approximately normal distribution of the population of differences (SD_1^2 minus SD_2^2) and a random selection from that population. The other applicable parametric test, the t-test, also requires normality of the population of differences of variances.

We have no knowledge about the population of differences of variances under these conditions, and therefore have no basis for an assumption of normality. It seemed wise, then, to forego the advantages of a stronger rejecting statement in order to avoid assumptions of normality.

For this reason, non-parametric tests were used. Since results for the same subject in different conditions constituted matched pairs of scores, the Wilcoxon Matched-Pairs Signed-Ranks Test was used. One advantage of this test is that it takes into account the magnitude of the difference between scores as well as the direction of the change. The interval scale properties of the data in the experiment are thus employed. The test is considered an excellent non-parametric analogue to the t-test and has comparable strength (17).

The Friedman Two-way Analysis of Variance was used to determine how much of the variance among the results was accounted for by each of three variables: Subject, Experimental condition and Order of Conditions. By comparing the relative amounts of variance due to each of a pair of variables this test measures the significance of the hypothesis that one of the pair accounts for all of the variance.

2. Results.

(a) Main experimental results. The results of statistical tests for increases in variability under the three experimental conditions are summarised in Tables I and II. A graph of these results is shown in Fig. 9. Ambulatory subjects showed significantly increased variability of discrimination both after one and two hours of exposure. The increases after one and two hours were also significant in the passive movement conditions but were not as large. A slight, statistically insignificant improvement of performance occured in the Recumbent condition; that is, there was a slight decrease in the standard deviations of the sets of thresholds.

One possible interpretation of these results is that proprioception from body and head movement, rather than efference, forms part of the feedback-loop described by Held's model.* Held's passive movement conditions in the Held and Bossom, the Held and Hein, and the Cohen and Held experiments (See page 6) were meant to show that proprioception from a passively moved muscle was not sufficient to cause the compensation or disorientation predicted by the feedback-loop model, which is an efference-reafference model. Complete confirmation of Held's inference that efference rather than proprioception is a necessary part of the loop would come from anesthetized limb or from lesion experiments. Such experiments would completely cut off proprioceptive stimulation and would have to be done on animals.

Another interpretation of the increased variability in the Ambulatory and Passive movement post-exposure results suggests that intersensory effects initiated by the extra load on the visual system during these conditions causes deterioration of dichotic time difference discrimination.** Such a proposal can not be examined directly from the results of this experiment without further experimentation to test it, but it seems of less importance at the present time for two reasons. Primarily,

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* Suggested by Dr. Eric Kandel of the Massachusetts Mental Health Center.

** Mentioned by Dr. Elliott Michler of the Massachusetts Mental Health Center.

"stress" is difficult to quantify, and therefore is difficult to define operationally in an experimental situation. Secondly, before the stress supposedly caused by certain conditions, may be studied conveniently, it is necessary to determine which specific components of the disarrangement conditions lead to increased variability. After this has been accomplished, the intersensory events inherent to the conditions may be studied.

The Passive movement condition was essentially an exploratory condition which does not thoroughly separate effects of head movements from body movements. For one thing, the frequency of head movements is not well specified in the instructions (See Appendix A). More important, the condition failed to distinguish between rotatory and translatory motion. Another experiment, therefore, must be designed to study the effects of four types of movements: head rotation, head translation, total body rotation and total body translation. Also, when the movements have been specified in this manner, it may be easier to determine frequency and amplitude of movements.

(b) The curve in Fig. 9 representing Ambulatory results shows a decrease in variability from the post 1 hour to the post 2 hour test. Although this difference is not statistically significant (See Table I) it was consistent for the sample of 12 subjects. One might, instead, expect an asymptotic curve, especially since the variability scores in the Cohen and Held disarrangement experiment (I) never showed a decrease with prolonged exposure. Furthermore, prolonged exposure in Held and Hein's rearrangement experiment produced an asymptotic curve. (II)

One of our subjects whose results in the Ambulatory condition approximated the average results for the whole sample was re-run in the Ambulatory condition after the experiment _per se_ was completed. Exposure was prolonged to three hours. The results are graphed in Fig. 10.

The curve levels out _after_ a large increase of variability during the first hour and a smaller decrease during the second hour. If head movements are, indeed, crucial for maintainance of localization and if, through fatigue, they decreased in frequency during the second hour of exposure, then one might expect a _decrease in deterioration_ (variability) of dichotic time difference discrimination during the second hour.* Of course, comment on the reasons for this second-hour effect is speculation, but this particular explanation is supported by the Passive movement condition results, where significantly increased variability resulted from self-produced head movement during exposure.

(_c_) The order effect. The significance of increases in variability on Days I, II and III, regardless of condition (Experimental conditions were permuted to control for order effects.) is shown in Table III. A graph of the results, when analyzed by Order instead of by Condition, is shown in Fig. 11. From Day I to Day III there is a progressively _decreasing_ deterioration after exposure. This is partly due to an increase in the baseline (pre-exposure) level of variability, which would make percentages of increase smaller, and partly to an actually smaller absolute

* Suggested by Dr. Richard Held of Brandeis University.

increase of variability. This effect was also noted for an experiment on speed perception by Freedman and Held (6). Two kinds of mechanisms may be working here: (a) Generally disturbing aspects of the exposure conditions which bother the subject on the first day but which he gets used to (hence, the smaller increase on Day II and Day III), and (b) A 'set' for the experimental situation which the subject learns on the first day and which re-entry to the laboratory triggers on Day II and Day III (hence, the higher baseline on those days.) Since the subjects presumably function normally outside the lab between sessions, the latter mechanism would have a steep gradient of generalization.

(d) Results of control conditions.

1. Subjects run in a condition identical to Ambulatory, but without listening to the "white" noise, did not show increased variability at the end of two hours of exposure. (See Fig. 12)

2. When Ambulatory subjects were kept for an additional 1/2 hour to rest, they returned to the baseline level of variability. This indicates that the duration of the effect in the Ambulatory condition is less than 30 minutes. If Ambulatory subjects walked continuously during the extra 1/2 hour, their discriminations at the end of the 30 minute period also were less variable than their pre-exposure test. (See Fig. 13)

3. Passive movement subjects in the same extra 1/2 hour conditions also returned to pre-exposure levels of discrimination. (See Fig. 14.)

4. That different subjects could give very dissimilar results in the same condition is indicated by the difference between the two curves in Fig. 13. Differences in the results for the same subject in the same condition on different days also occurred. One subject who had shown a small increase in variability in the Ambulatory condition showed an even smaller increase when he was re-run after the experiment *per se*. Two other subjects with very small changes in the Ambulatory condition demonstrated very large changes in their re-run of that condition, and returned to the baseline level of discrimination with an extra 1/2 hour walking without noise.

Another subject who had shown some increase in variability in the Recumbent condition was re-run in a control condition in which he lay on a bed with no "white" noise. He was allowed to read. At the end of one hour, he showed a 200% increase in the variability of his discriminations. During the second hour he walked up and down the corridor for alternate five-minute periods, also with no noise. At the end of this hour, his discriminations were at the baseline level of variability. This subject apparently had to have strong contact with a normal environment in order to maintain accurate auditory localization.

CHAPTER IV.

Apparent Intensity Balancing

As mentioned in Chapter III, the results of two subjects who completed the experiment could not be included in the calculations of experimental results because on some of the post-exposure dichotic time difference discrimination tests they continued to say "left" when the right signal was leading by 100 microseconds (See Fig. 5) or "right" when the left signal was leading by the maximum amount.* No numerical thresholds were calculable for these tests, so the data had to be discarded. To determine the effect of changes of intensity balancing on the mean of the thresholds of dichotic time difference discrimination, a procedure separate from the experimental work was carried out. First, the changes in apparent intensity balancing caused by changes in dichotic time difference were studied. (See Fig. 15.) Then the procedure was reversed, studying the shifts of the subjective midpoint in microseconds as a function of changes in dichotic intensity difference.

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* This directional shift is probably due to differential adaptation to the loud "white" noise, because of (a) the crude mechanisms for adjusting "white" noise intensities, and/or (b) a difference in dichotic intensity balancing between the absolute intensity level of the "white" noise and the level of the test signal.

(See Fig. 16.) In each case the results approximated a straight line, but an experiment covering a wider range of dichotic intensity and time differences needs to be completed before inferences can be made about the shape of the curve.

CHAPTER V.

Conclusions

Following the experiments of Held and Bossom (9), Held and Hein (10, 11) and Cohen and Held (1), this experiment indicates that self-produced motion during the exposure period as well as sensory information about the results of this motion is necessary to produce increases in variability of dichotic time difference discrimination. Fatigue, distraction and boredom do not have significant effects. The study of intersensory effects and of the role of proprioceptive stimuli and an adequate breakdown of the components of head and total body movement all require further experimentation.

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TABLE I. Significance of differences in variability from pre-exposure to post-exposure tests of dichotic time difference discrimination, under varying conditions of motility.*

SIGNIFICANCE OF INCREASED VARIABILITY

	From Pre- to Post 1 hr.	From Pre- to Post 2 hr.	From Post 1 to Post 2 hr.
Ambulatory	$p < .005$	.005	N.S.
Recumbent	N.S.	N.S.	N.S.
Passive movement	.01	.025	N.S.

* Wilcoxon Matched-Pairs Signed-Ranks Test, one-tailed.

TABLE II. Significance of the amount of variance in the experimental results accounted for by one of the variables , when they (Condition, Subject, and Order) are paired against one another. **

<u>Condition</u> <u>vs.</u> <u>Subject</u> variance:	The Experimental Condition variable accounts for variance in the results, significant at the	.005 level.
<u>Order</u> <u>vs.</u> <u>Subject</u> variance:	The Order variable accounts for the variance in the results, significant at the	.05 level
<u>Condition</u> <u>vs.</u> <u>Order</u> variance:	The Experimental Condition variable accounts for variance in the results, significant at the	.10 level

** Friedman Two-Way Analysis of Variance.

TABLE III. Significance of differences in variability from pre-exposure to post-exposure tests of dichotic time difference discrimination, on different experimental days (regardless of experimental condition.)*

	SIGNIFICANCE OF INCREASED VARIABILITY		
	From Pre- to Post 1 hr.	From Pre- to Post 2 hr.	From Post 1 to Post 2 hr.
Day I	$p < .005$	.005	.05 **
Day II	.025	.05	N.S.
Day III	N.S.	N.S.	N.S.

* Wilcoxon Matched-Pairs Signed-Ranks Test, one-tailed.

** The Day I Post-1 to Post-2 change in variability was a <u>decrease</u> (improvement in performance), significant at .05.

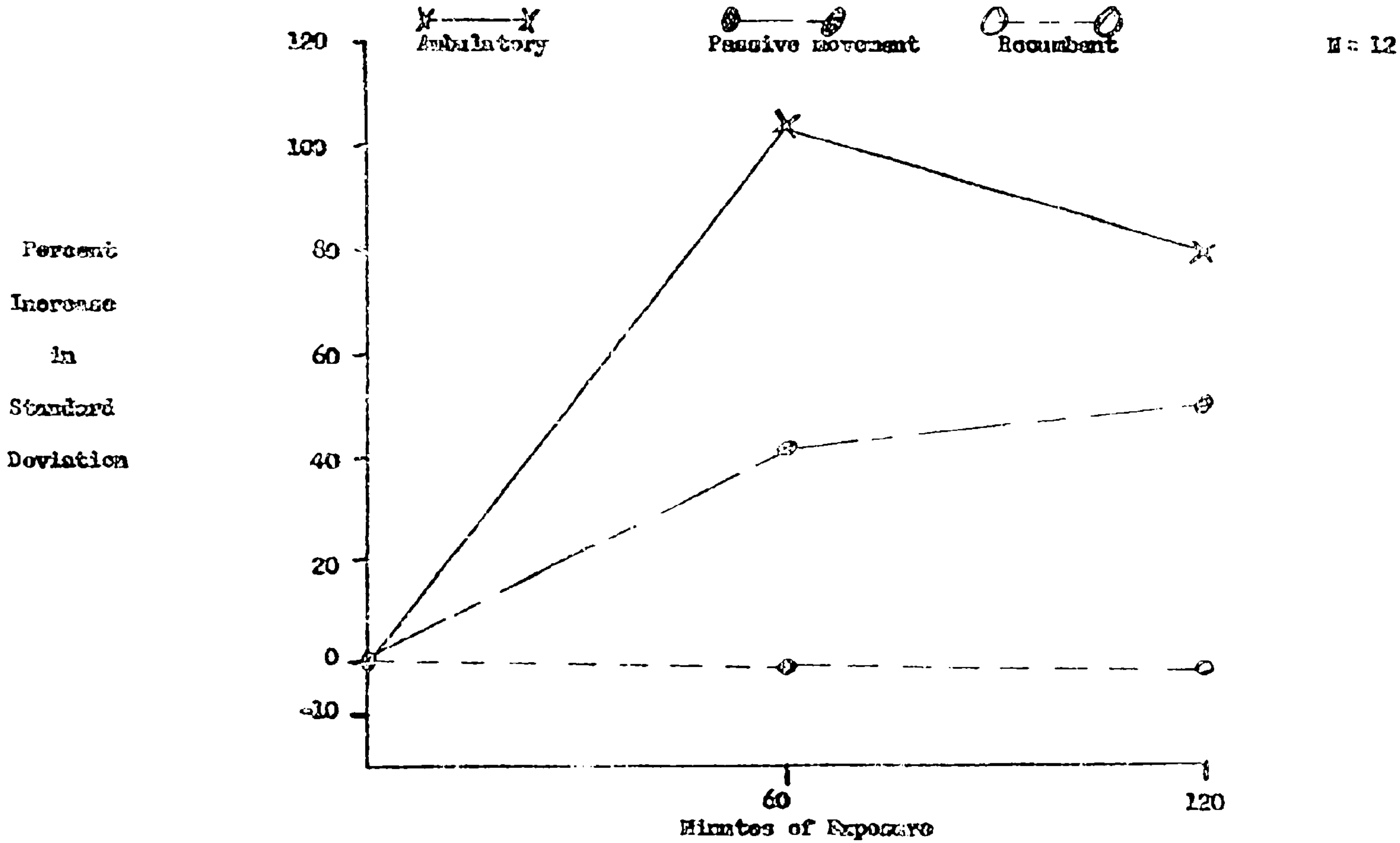

Fig. 9. Effects of exposure to "white noise" on variability of auditory localization, under varying conditions of motility.

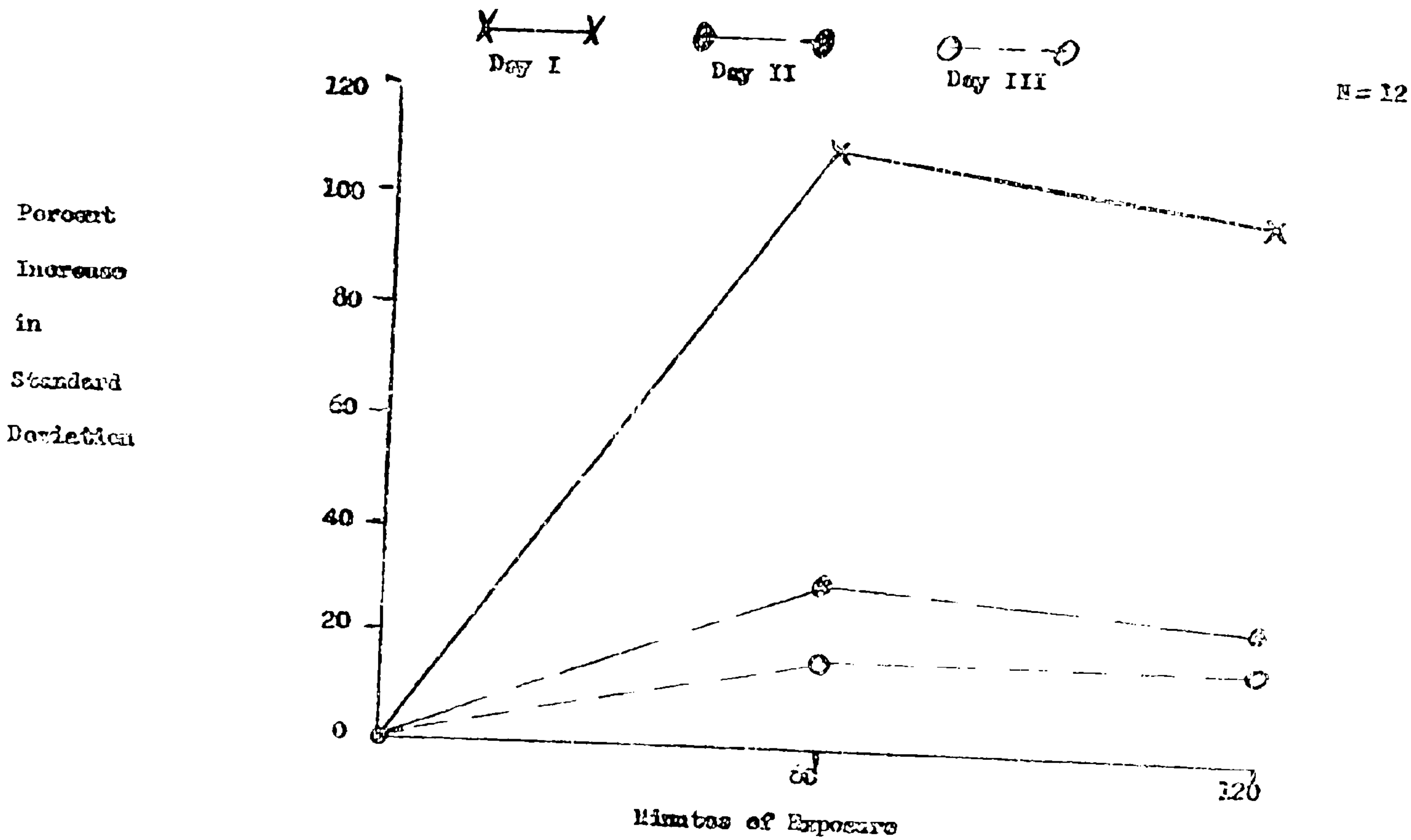

Fig. 11. Effects of exposure to "white noise" on variability of auditory localization, according to order of experimental sessions.

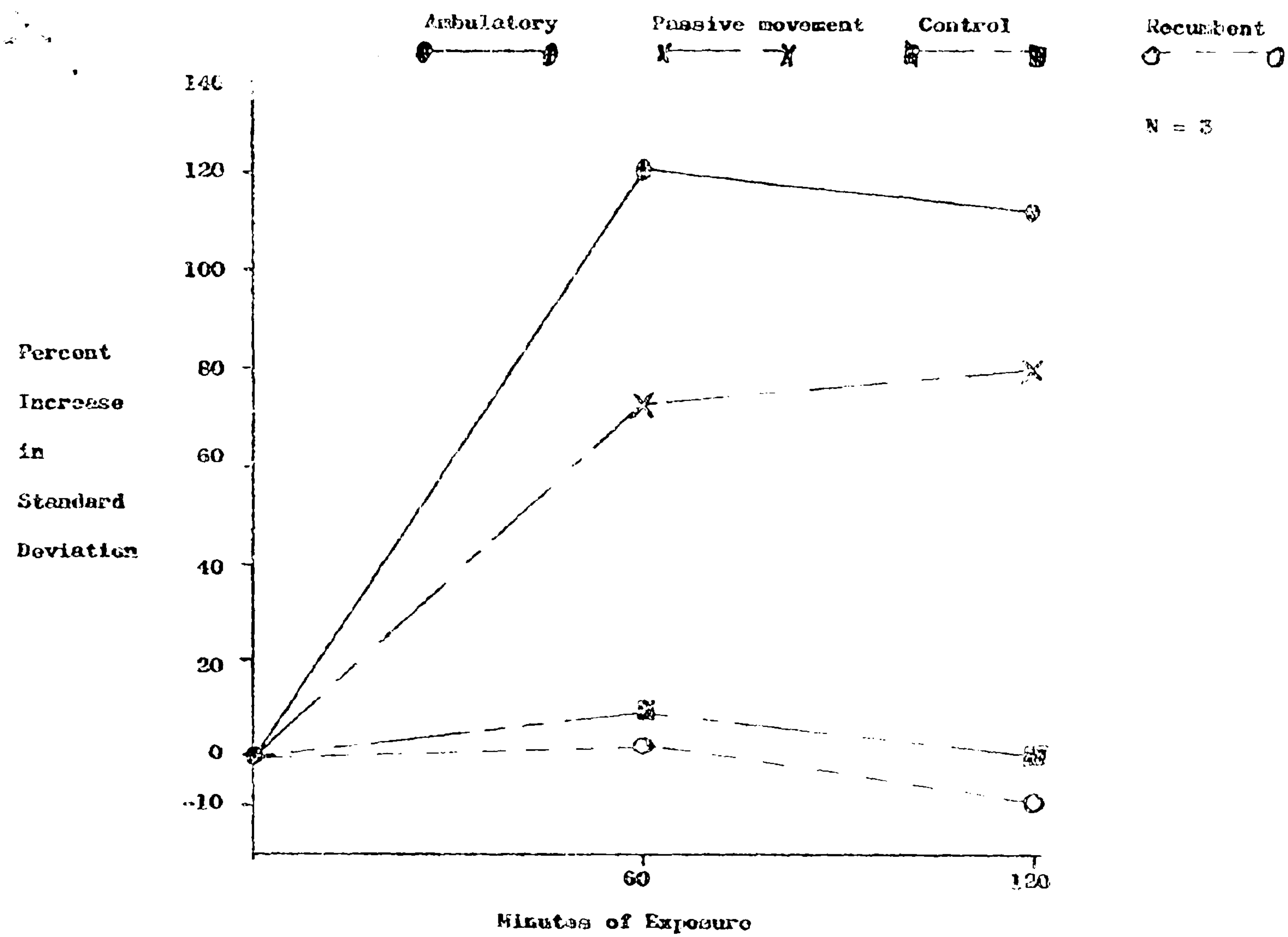

Fig. 12. Results for three subjects who were run in a separate control condition as well as in the regular experiment. The control condition was identical to the Ambulatory except that the subject's hearing was unimpeded.

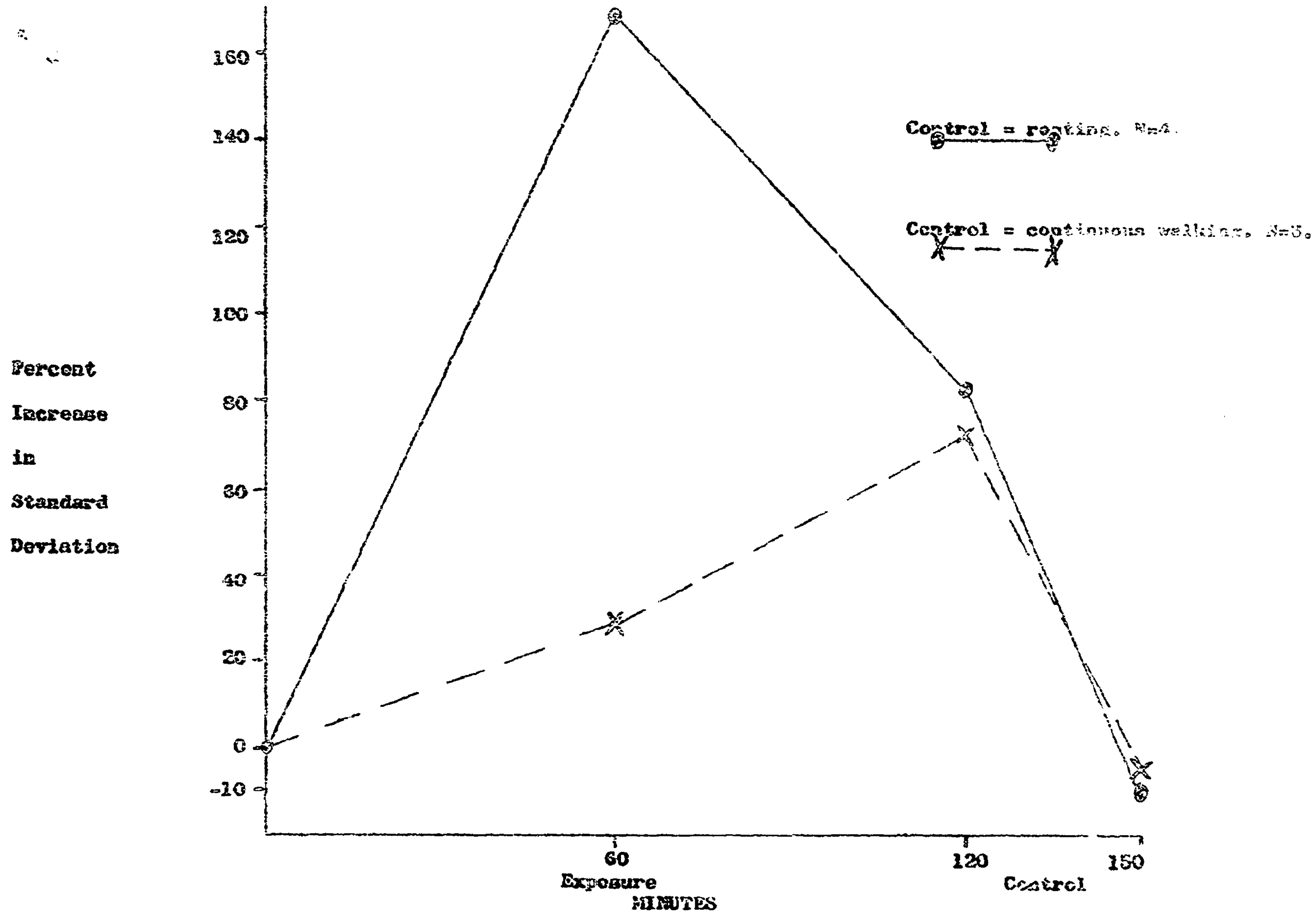

Fig. 13. Results in the Ambulatory condition for subjects who were kept for an extra ½ hour control.

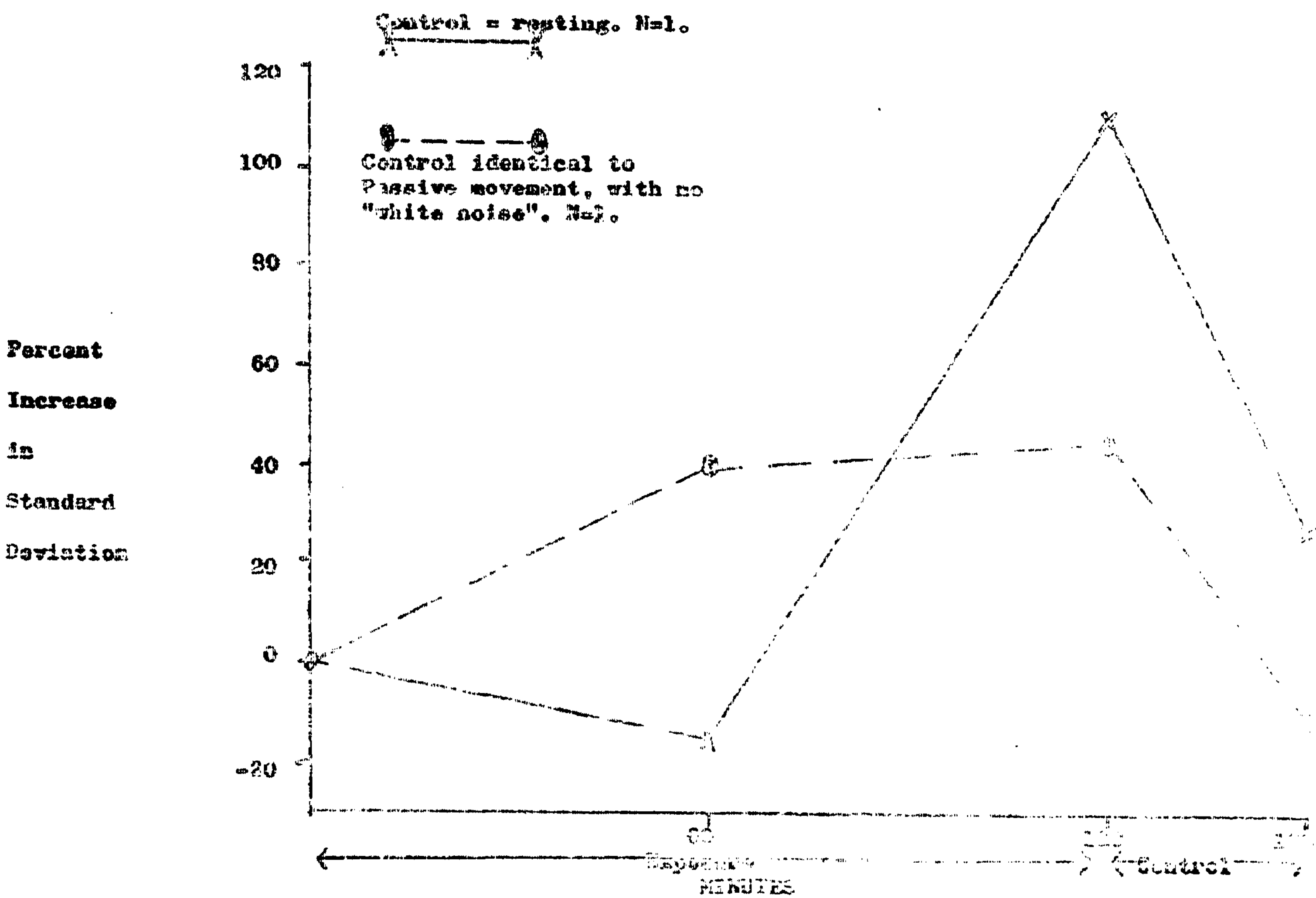

Fig. 14. Results in the Passive movement condition for 2 subjects who were [illegible] for an extra ½ hour control.

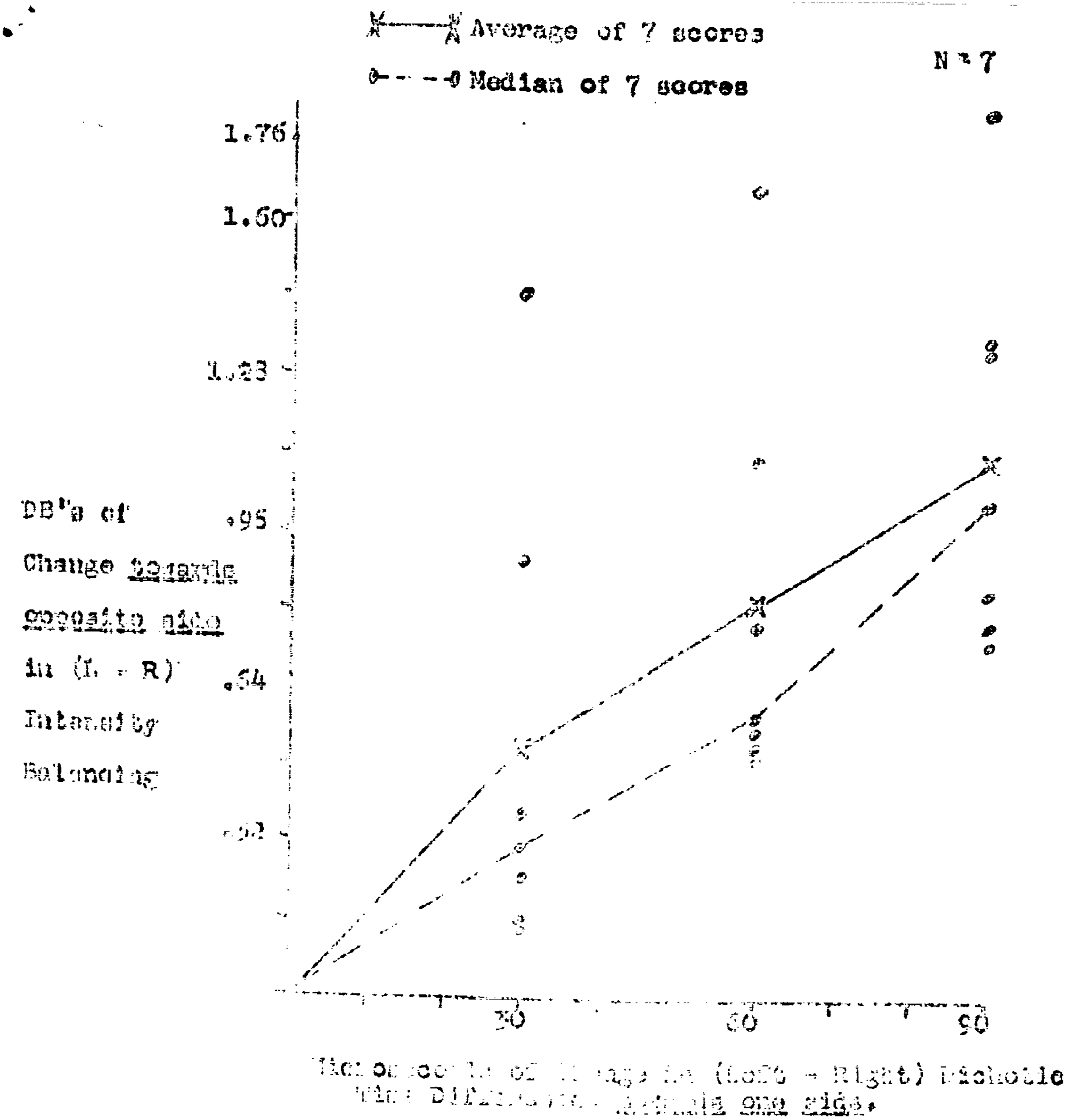

Fig. 15. [illegible] differences [illegible] differences: What dichotic [illegible] difference is [illegible] to offset a given dichotic [illegible] side leads in time, the [illegible]

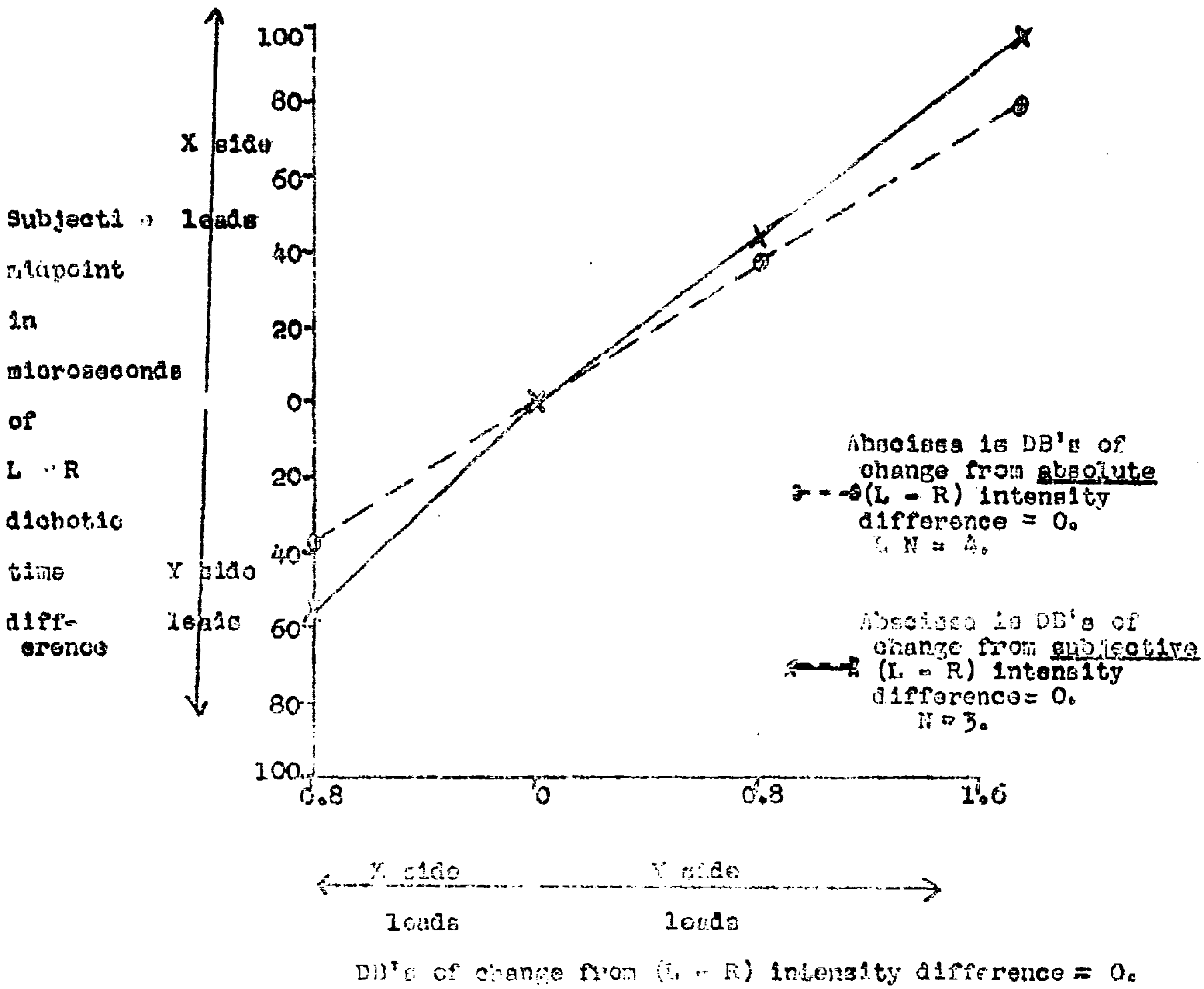

Fig. 16. Intensity difference versus time differences. What dichotic time difference is required to offset a given dichotic intensity difference. Changes from the intensity midpoint with the left louder shift the subjective midpoint in microseconds toward the right, and *vice versa*. One curve is a function of changes from an absolute intensity midpoint (I.E. the same voltage for the left and right ear clicks), and the other curve is a function of changes from an intensity midpoint set by the subject.

APPENDIX A

INSTRUCTIONS TO SUBJECTS

Apparent Intensity Balancing: "This is a task in which you're to report whether a sound is left, right, or center. I will repeat the sound until you're ready to report; that is, when you think you've located it, give the report. When you report a sound as center, it should be a point exactly in the center of your head; center is considered as a point, not a general area. It will help to concentrate if you keep your head still and your eyes closed. Are you ready?"

After the subject has reported: "Turn this dial (indicating) until the sound is exactly in the center of your head. Turning the dial this direction will make the sound move_______. Don't worry about over-shooting the center mark; if you do, you can turn it back to center by turning the dial in the opposite direction."

Dichotic Time Discriminations: "This, again, is a task in which you're to report whether a sound is in the left, right or center of your head. Again, center is considered to be a point and not a general area in the center of your head. Report center only if the sound is exactly at a point in the middle of your head. If it is even 'leaning' to one side, then report that side. I will give the sound once, and you should report unless you're not sure. If so, ask me to repeat the sound, and I will. Keep your head steady and your eyes closed throughout the test. Are you ready?"

Exposure: "Turn the red dials on the radios until the sound is just loud enough so that you can't hear me talking. Each dial controls the loudness for one ear. When you've adjusted the loudness so that you can hear nothing but the noise, make sure that the noise in the two ears sounds equally loud. After that, the dials will be left alone. During the next hour, you're......

Recumbent "....to lie quietly on the bed. Keep your body as still as possible, and it's essential that you keep your head absolutely still. You may move your hands and your eyeballs while reading, but keep your head still. Do you understand?"**

** After the Post 1 hour test, I showed them a card on which was printed, "Same instructions for one more hour."

Ambulatory "....to walk up and down the hall in alternate five-minute intervals. During the five-minute rests you may sit and read. You should time yourself by the hall clock and keep as close to the five-minute intervals as possible. Do you understand?"

Passive movement "....to sit in the wheelchair, keeping your body still. I will wheel you up and down the hall in alternate five-minute intervals, and during these times you should rotate your head back and forth (demonstrating) as though you wanted to look in all the offices. During the resting periods you may read. Do you understand?"

Ambulatory Control: "During the next hour you're to walk up and down the hall in alternate five-minute intervals. You may read only during the five-minute rests. Do you understand?"